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SEDIMENT SAMPLING IN TIDAL WATERWAYS

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SEDIMENT SAMPLING IN TIDAL WATERWAYS

E. A. Schultz,[1] A.M. ASCE

Large amounts of public and private funds are expended annually for maintenance dredging of navigation channels in tidal waterways and in the adjacent berthing areas. It is only natural that as a consequence many small-scale hydraulic model investigations and a number of prototype field investigations have been undertaken to study ways and means of eliminating or mitigating the shoaling problem, and in the process, to determine the nature and causes of the shoaling and the sources of the material which forms the shoals. To this end some of the field programs have included the collection of samples of suspended sediment from the tidal waterways in both limited and extensive quantities. On occasion the field investigations have been entered into lightly or without benefit of competent advice, and extensive sampling has been performed without the investigator recognizing how representative the results might be or without giving much thought as to how the results will be used. This paper is devoted to that aspect of prototype investigations concerned with sampling of suspended sediment in tidal waterways, dealing specifically with the question of accuracy of measurements of total sediment-discharge in given cross sections of an estuary, and with the value of a few well-planned and -executed operations to provide information on the hydraulic and sediment characteristics of the waterway.

In some instances the investigator may feel that solution of the shoaling problem requires knowledge of the total discharge of sediment in an estuary, but he should recognize that the procurement of such information by direct observation is a Herculean task, and it is impracticable, if not impossible, to obtain results with the same degree of accuracy and reliability as are obtained from similar measurements in an upland stream where the flow is uni-directional and sensibly constant and the water is of homogeneous density. This conclusion was reached by the Committee on Tidal Hydraulics of the Corps of Engineers in a long overdue study of the problems associated with the measurements of the sediment load transported by tidal waterways, and it was generally concurred in by many of the 45 organizations and individuals provided with the opportunity of reviewing and commenting upon a brief of the problem furnished by the Committee[2].

The many unique characteristics of an estuary which complicate the problem of measuring the total sediment discharge are listed in the above-mentioned brief as follows:

"1. The discharge is rapidly variable.

1. Hydraulic Engineer, Charleston District, Corps of Engineers, U. S. Army, Charleston, South Carolina.
2. "Sediment Discharge Measurements in Tidal Waterways," Committee on Tidal Hydraulics, Corps of Engineers, U. S. Army. (Scheduled for publishing in 1954 as a bulletin of the Committee.)

"2. Velocity distribution varies in the vertical and the horizontal independently of the discharge variation.

"3. The complex regimen existing for the flow in one direction is discarded every six hours (approximately) and an equally complex regimen, but of different characteristics, is set up for flow in the opposite direction.

"4. Successive "cycles" are not identical -- in fact, are frequently quite different.

"5. The water in some reach of every estuary is not of homogeneous density, nor is the difference constant."

The brief states . . . . . "It is readily apparent that a determination of the suspended sediment content made at the surface of an estuary at hour 1200 is not comparable with an observation at the bottom at hour 1215. The discharge might have changed 25% in 15 minutes. Likewise, a sample taken at 1215 at the bottom at a given location along the cross-section line can be related logically to one taken at the bottom somewhere else along the line in this respect only: they both contain water and sediment taken from the same estuary."

The instantaneous fluctuation of the current velocity is another factor which affects the results. It has been demonstrated that successive short-time observations with a current meter -- of the order of 40 to 70 seconds -- at one- and two-minute intervals over a period of several minutes, will produce velocities which vary as much as 20%.

All of the above factors contribute materially to the difficulties of measuring accurately the quantity of sediment discharge in tidal waterways, but certain research conducted by the Charleston, South Carolina, District of the Corps of Engineers, has revealed that there is still another contributing factor as important, or more important, than the ever-changing tidal flow and density currents mentioned above. This factor is the considerable variation in concentration of the suspended sediment both temporally and spatially in tidal waterways. The research has indicated that variations in sediment concentration can be expected ranging from a few percent to 1,000 percent, or more, for samples taken only a few feet or a few minutes apart. Considerable of the sediment, no doubt, moves in slugs, so to speak, and this phenomenon has frequently been observed in the surface of the harbor both under natural conditions and in connection with maintenance dredging operations. The sediment is not mixed and distributed as uniformly throughout the tidal water as might be supposed. The variations in tidal flow, unquestionably, are largely responsible for the variations in sediment concentration, and the two phenomena cannot be disassociated from one another. Apparently, however, the order of variation of sediment concentration is greater, and since sediment load is the product of the sediment concentration and the discharge, it has more influence on the computation results. In order to clarify the several significant conclusions which are to be drawn from this revelation, it is pertinent to describe briefly some of the sampling operations which were conducted in Charleston Harbor, and the objectives of these operations.

For several years, from 1948 through 1953, the Charleston District of the Corps of Engineers conducted extensive investigations of the harbor, both in the prototype and on a small-scale hydraulic model, to determine the causes and remedial measures for the greatly increased rate of shoaling in the inner-harbor navigation channels. These investigations embraced many fields of

work, but only the suspended sediment sampling and related operations in the lower salt-water reaches of the harbor are within the scope of the subject matter under discussion. The operations in the lower harbor were conducted with the objective of learning as much as possible about the hydraulic, saline, and sedimentation characteristics of the harbor; to determine the nature, mechanics, and causes of the shoaling phenomena; and to identify, if possible, the sources of shoaling and their significance. These objectives involved, among other things, determination of the quantity of sediment load in transport throughout the harbor; which in turn involved observations of tidal heights, magnitudes and directions of current velocities, and the procurement of samples of suspended sediment.

Advisors on the studies recommended against a series of disconnected comprehensive sampling operations on different days on various ranges throughout the harbor, using a number of samplers simultaneously in each cross section. Instead, they suggested a program of correlated operations in which five or six ranges would be occupied and worked simultaneously, but with only one sampler in each cross section, located at the centroid of discharge, or at two centroids -- one each for ebb and flood -- if required. However, it was difficult to select these control stations from examination of the plotted cross sections alone, and even more difficult to determine the probable locations of representative sediment concentrations and sediment discharges. Therefore, the original plan of sampling each cross section separately and comprehensively for one condition of tide was adopted. It was hoped that these operations would provide the data required to select the centroids of sediment discharge, after which the recommended plan would be followed and repeated for several different tidal conditions. These operations were conducted as follows: Each cross section was explored throughout a complete tidal cycle. From three to five US P-46 point-integrating suspended sediment samplers were distributed across the range and operated simultaneously, first in the surface, then at various increments of depth in succession to the bottom. A step prior to obtaining each sample was measuring of the velocity required both for computing the discharge and sediment discharge and for determining the filling rate of the sampler. From 15 to 20 minutes were required to explore and sample the entire cross section in this fashion, and the process was repeated hourly during the tidal cycle, with extra observations of velocities only on the half-hour. The sediment discharge was then computed from these field measurements and the laboratory analyses of the samples.

Examination of these data showed that the sediment concentration was very erratic, both with respect to depth and width, and caused concern over the validity of the measurements. It was reasonable to assume that had different stations on the range been occupied, different values for sediment concentration, and consequently, for sediment discharge, would have been obtained. Thus, the sampling of a half a dozen, or so, verticals in a cross section would not provide an accurate representation of the sediment load passing that cross section.

A special research operation was therefore planned and conducted with the aim of collecting sediment data which would establish the validity of the above assumption and be useful in evaluation of the suspended-load measurements by the methods being employed. Figure 1 illustrates the technique employed in this special operation. At the top of the figure, for comparison, is a typical layout of a cross section and five samplers for a regular suspended-load measuring operation. In STEP 1, one bateau complete with sampler, current meter and other appurtenant gear was anchored over this cross section on one of the

established stations -- in this case, Station 6+50 -- and four other bateaux similarly equipped were brought alongside and anchored; all touching each other. This placed the samplers as closely together as the widths of the bateaux would permit, the distance between outside samplers being 20 feet. In all steps of the operation being described, five samples, making up a set, were obtained simultaneously with US P-46 samplers. The velocity of the current was measured immediately before obtaining each set of samples in order to determine the filling rate of the samplers. In STEP 1, sets were obtained at 4-minute intervals, the first set at the surface and successive sets below the surface at 8-foot depth increments, and the last two sets were obtained 2 and 1 feet above the bottom, respectively. The whole procedure was then repeated twice more, for a total of three runs. The objective in this instance was to determine variation of the sediment concentration with respect to lateral distance. In STEP 2, sets of samples were obtained at 3-minute intervals, and the sequence was different. Here, four successive sets of samples were obtained at the same depth, before proceeding to the next depth for four more sets. The depths sampled were at the surface and 8, 16, 24, and 28 feet below the surface. The objective in this instance was to determine variation of the sediment concentration with respect to time. STEP 3 differed from the others in that single samples were obtained simultaneously at five different depths. The objective here was to determine variation in sediment concentration both with respect to depth and time. STEP 4 was the same as STEP 1, except that the lateral spacing of individual samplers was increased from 5 to 100 feet.

Figures 2 to 5 contain the suspended sediment results, and the applicable field procedure, for each of the four steps of the operation. Figure 2, STEP 1, indicates the spatial variation in sediment concentration which existed. Each of the three runs show five different answers at each depth for each of the five points spaced five feet apart. The least variation was found in the upper stratum where concentrations were of the order of 8 to 38 p.p.m.; and maximum deviations from the low to the high values in the surface and at 8-foot depth ranged from 50 to 220 percent. The maximum variation was found at a depth one foot from the bottom where concentrations were of the order of 20 to 200 p.p.m.; and in the third run, the high value was 640 percent greater than the low value.

Figure 3, STEP 2, indicates the temporal variation in sediment concentration which existed. Although successive values for four of the samplers in the surface were in fair agreement, sampler "D" produced values ranging from 11 to 48 p.p.m., or a deviation from the low to the high value of 340 percent, within a period of 3 minutes. As in the case of STEP 1, maximum variations were found near the bottom. At 24-foot depth sampler "B" produced values ranging from 98 to 306 p.p.m., and at 28-foot depth sampler "E" produced values ranging from 38 to 138 p.p.m., within a period of 3 minutes. The former results in a deviation from the low to the high value of 210 percent, and the latter, of 260 percent. These deviations are increased to 670 and 370 percent, respectively, if the maximum and minimum values are considered at each depth, but irrespective of the particular samplers which produced the results. This is a reasonable consideration since from a practicable standpoint the close spacing of the samplers, in effect, puts them in the same vertical; the 3-minute sampling interval, in effect, makes successive samples nearly instantaneous; and the five samplers are supposed to be equally accurate.

The results from STEPS 3 and 4, Figures 4 and 5, show the same trends as the results from the first two steps. STEP 4 with sampler spacing of 100 feet, like STEP 1 with sampler spacing of 5 feet, indicates the spatial variation in

sediment concentration which existed. However, the order of variation, particularly in the very lowest stratum, was greater. At a depth one foot from the bottom the values ranged from 8 to 6,085 p.p.m., 17 to 335 p.p.m., and 28 to 347 p.p.m., for Runs 1, 2, and 3, respectively. Overlooking the results for Run 1 which seem to be out of line, the corresponding deviations from the low to the high values for Runs 2 and 3 are 1,870 and 1,140 percent, respectively. It has been suggested that the excessive variation shown possibly could be attributed to the samplers resting in the soft bottom of the estuary. However, the investigators are reasonably certain that this was not the case. There are several ways of determining this, one of them being that under these circumstances the sampler would come up empty.

As a result of the findings described herein, it is concluded that the considerable variation in the sediment concentration which exists in tidal waterways, especially in those cases where the material is predominantly silt and clay particles, makes it impracticable, if not impossible, to measure the quantity of sediment discharge accurately. This, of course, is the same conclusion reached by the Committee on Tidal Hydraulics, based on the ever-changing tidal flow, density currents, and other factors mentioned earlier in this paper.

The question arises as to whether knowledge of the total discharge of sediment in an estuary by direct observation is worth the effort. The writer believes that estimates or approximations of the sediment load have their value and that the direct observations made in this connection are worth the cost and effort, provided that the shoaling problem is important enough, provided that other needed information can be obtained as a result of or in conjunction with these sediment-sampling discharge-measuring operations, and so long as the number of operations are kept within reasonable bounds.

After the investigator has completed a few exploratory operations and learned something of the mechanics of sediment transport in the tidal waterway with which he is concerned, he will have to decide whether knowledge of the sediment load is necessary, and if so, whether accurate answers are necessary or whether reasonable approximations will suffice for his problem. The main point is that he recognizes the limitations of the data. If he decides that information on the sediment load is desirable, he should limit the number of cross sections to be explored, and work these for several conditions of tidal and fresh-water flow in order to obtain more representative data and establish that the resulting trends of the operations are in line with each other. The implications of the variations in sediment concentration were recognized early in the course of the Charleston Harbor investigation. Nevertheless, it was decided to conduct a limited number of suspended load operations, since it was felt that approximate answers of quantity of material in transport would help supply some of the answers to the problems. For example, the three main tributaries to Charleston Harbor are tidal throughout most of their lengths, so it was out of the question to measure the sediment loads above the head of tide. However, measurements at the mouths of the tributaries provided data to support the conclusion that one tributary is a significant source of potential shoaling material and the other two are not. These types of measurements also showed that the net transfer of material in a cross section may be seaward, but the net transfer at the bottom may be inland; and the measurements gave some idea of the quantities moving in the upper and lower zones. Furthermore, these operations provided information which was helpful to an understanding of the mechanics of sediment transport in the harbor. For example, it was learned that the suspended sediment in a tidal waterway, unlike that in a river where it stays in suspension most of the time, alternately goes to the

bottom with the slackening current and rises to the higher strata with the accelerating current. Finally, since other observations were made concurrently with the sampling, these operations were the means by which much was learned about the hydraulic and saline characteristics of the harbor.

Notwithstanding the above remarks, the implications of the variations in sediment concentration in tidal waterways should be recognized. It appears that there are sufficient grounds for questioning the validity of the procedure of measuring the sediment discharge in a cross section by operating one sampler in a single vertical which has been previously rated, as in stream-gaging operations; and that not much better answers can be obtained from the "shuttle" procedure, in which one vertical is continuously occupied and others are occupied part time by shuttling back and forth between them. Finally, good correlation is probably not possible between data obtained simultaneously on several ranges distributed throughout the saline portion of the tidal waterway. The variation in sediment rules out the so-called "control-net" scheme for correlating sampling results, in which one or two centroids or control verticals are established on each range and then occupied in subsequent operations calling for simultaneous measurements on perhaps five or six ranges. It is believed that strictly valid comparisons cannot be made of data obtained simultaneously on two wide ranges defining a given reach of a channel where, for example, three, four, or five verticals on each range are explored. These types of operations have their value, of course, but non-recognition of the sediment variation could lead to erroneous conclusions on such matters as the net movement of sediment load, pick-up or deposition in various reaches of the channel, etc.

REFERENCE

"Sediment Discharge Measurements in Tidal Waterways," Committee on Tidal Hydraulics, Corps of Engineers, U. S. Army. (Scheduled for publishing in 1954 as a bulletin of the Committee.)

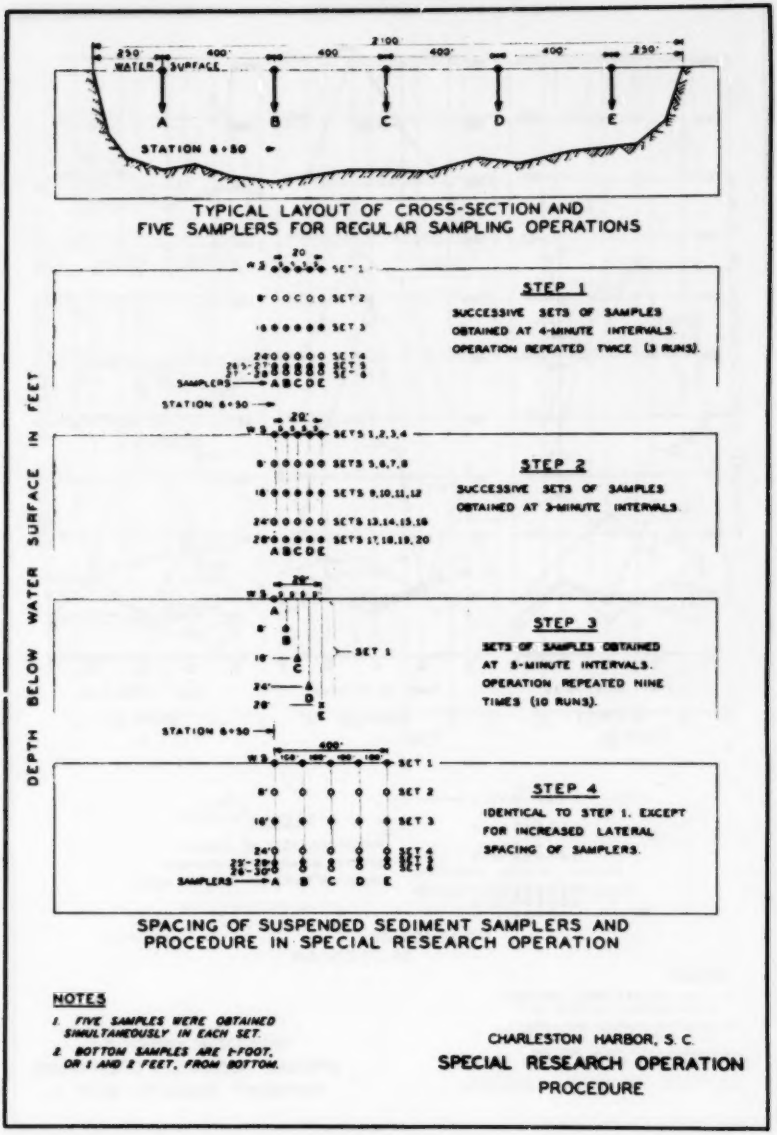
2100'
250'
400'
400'
400'
400'
250'
WATER SURFACE
A
B
C
D
E
STATION 6+50
TYPICAL LAYOUT OF CROSS-SECTION AND
FIVE SAMPLERS FOR REGULAR SAMPLING OPERATIONS
DEPTH BELOW WATER SURFACE IN FEET
20'
SET 1
SET 2
SET 3
SET 4
SET 5
SET 6
SAMPLERS → A B C D E
STATION 6+50
STEP 1
SUCCESSIVE SETS OF SAMPLES OBTAINED AT 4-MINUTE INTERVALS. OPERATION REPEATED TWICE (3 RUNS).
SETS 1,2,3,4
SETS 5,6,7,8
SETS 9,10,11,12
SETS 13,14,15,16
SETS 17,18,19,20
STEP 2
SUCCESSIVE SETS OF SAMPLES OBTAINED AT 3-MINUTE INTERVALS.
STEP 3
SETS OF SAMPLES OBTAINED AT 5-MINUTE INTERVALS. OPERATION REPEATED NINE TIMES (10 RUNS).
400'
STEP 4
IDENTICAL TO STEP 1, EXCEPT FOR INCREASED LATERAL SPACING OF SAMPLERS.
SPACING OF SUSPENDED SEDIMENT SAMPLERS AND
PROCEDURE IN SPECIAL RESEARCH OPERATION
NOTES
1. FIVE SAMPLES WERE OBTAINED SIMULTANEOUSLY IN EACH SET.
2. BOTTOM SAMPLES ARE 1-FOOT, OR 1 AND 2 FEET, FROM BOTTOM.
CHARLESTON HARBOR, S. C.
SPECIAL RESEARCH OPERATION
PROCEDURE

Figure 1

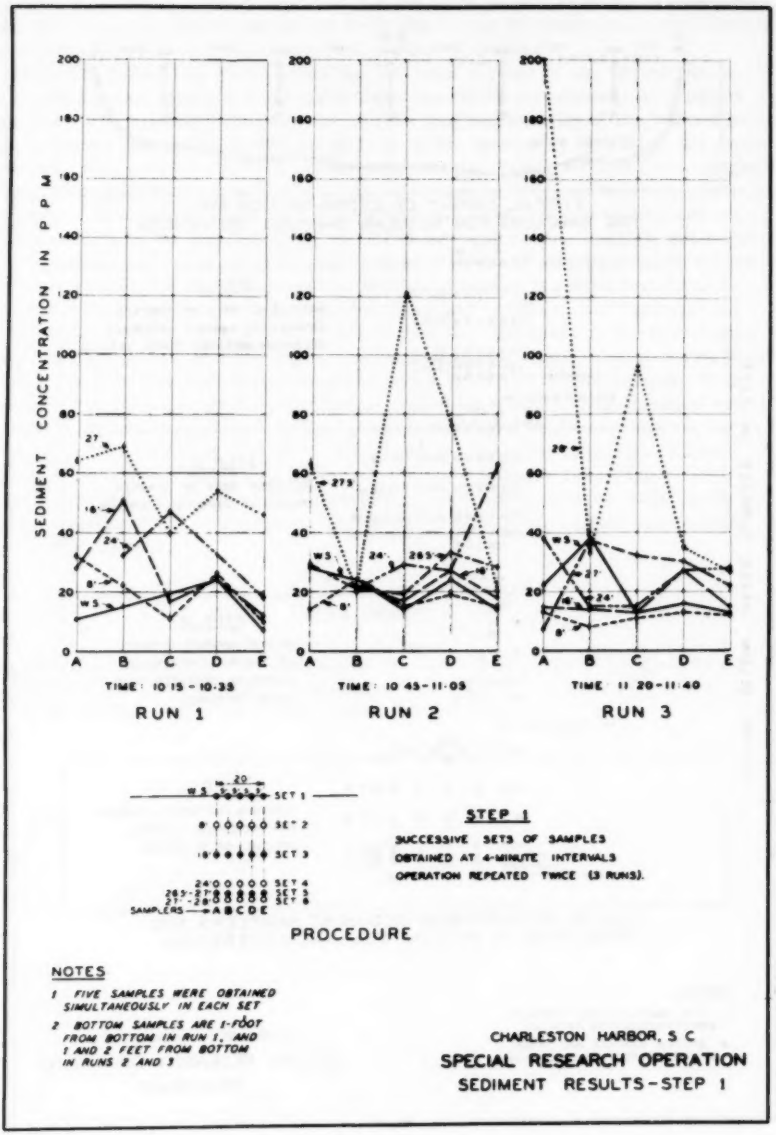
SEDIMENT CONCENTRATION IN P P M
TIME: 10 15 - 10-35
RUN 1
TIME: 10 45-11-05
RUN 2
TIME 11 20-11 40
RUN 3
STEP 1
SUCCESSIVE SETS OF SAMPLES OBTAINED AT 4-MINUTE INTERVALS OPERATION REPEATED TWICE (3 RUNS).
SAMPLERS → A B C D E
PROCEDURE
NOTES
1 FIVE SAMPLES WERE OBTAINED SIMULTANEOUSLY IN EACH SET
2 BOTTOM SAMPLES ARE 1-FOOT FROM BOTTOM IN RUN 1, AND 1 AND 2 FEET FROM BOTTOM IN RUNS 2 AND 3
CHARLESTON HARBOR, S C
SPECIAL RESEARCH OPERATION
SEDIMENT RESULTS-STEP 1

Figure 2

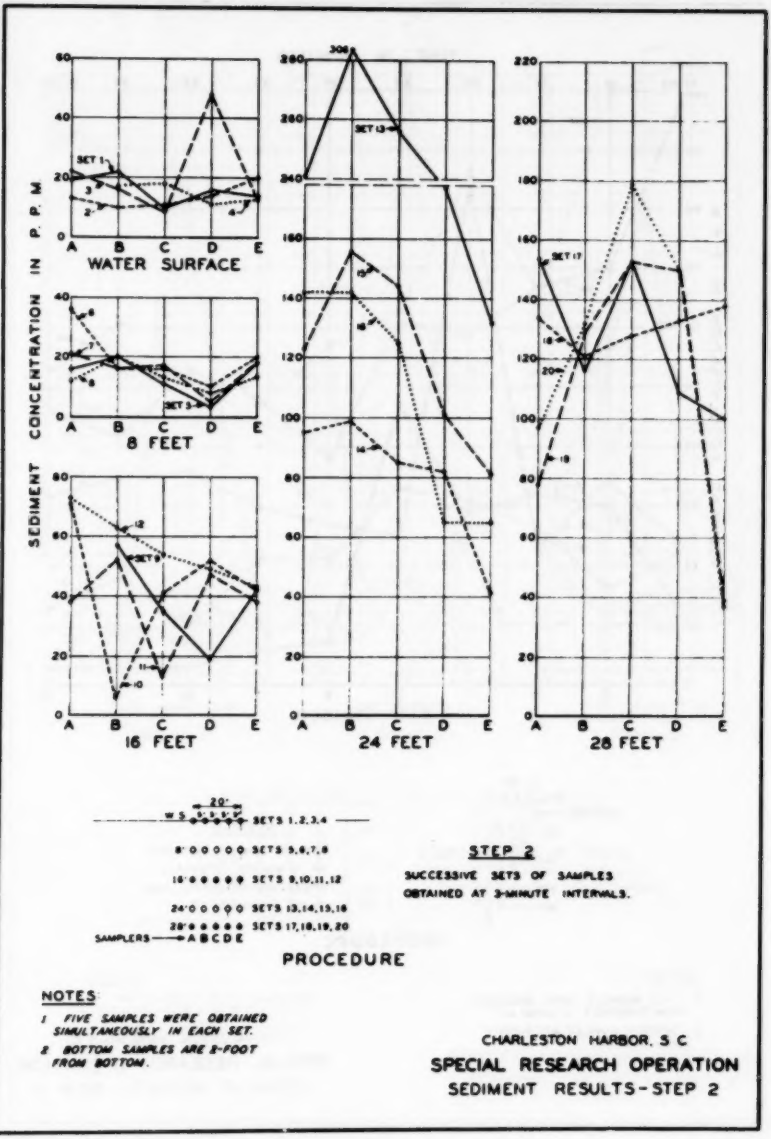
SEDIMENT CONCENTRATION IN P.P.M
WATER SURFACE
8 FEET
16 FEET
24 FEET
28 FEET
A B C D E
SET 1
SET 13
SET 17
SET 9
20'
SETS 1,2,3,4
SETS 5,6,7,8
SETS 9,10,11,12
SETS 13,14,15,16
SETS 17,18,19,20
SAMPLERS A B C D E
PROCEDURE
STEP 2
SUCCESSIVE SETS OF SAMPLES OBTAINED AT 3-MINUTE INTERVALS.
NOTES
1 FIVE SAMPLES WERE OBTAINED SIMULTANEOUSLY IN EACH SET.
2 BOTTOM SAMPLES ARE 2-FOOT FROM BOTTOM.
CHARLESTON HARBOR, S C
SPECIAL RESEARCH OPERATION
SEDIMENT RESULTS - STEP 2

Figure 3

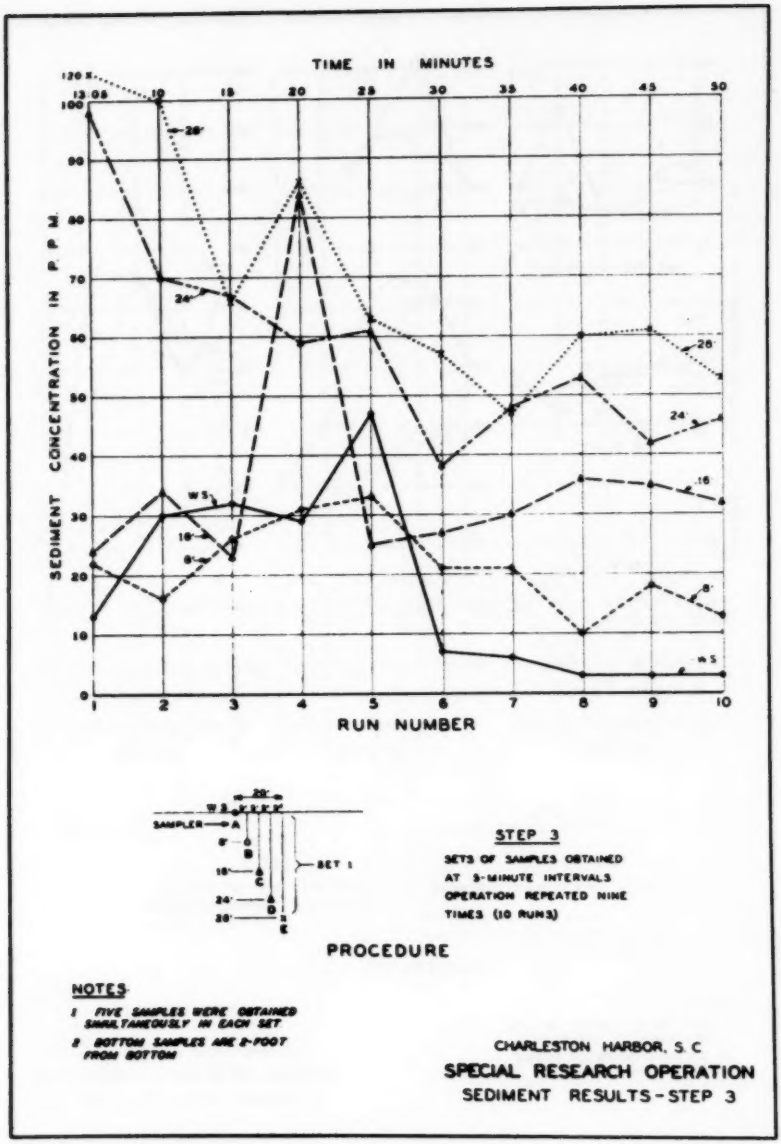
TIME IN MINUTES
SEDIMENT CONCENTRATION IN P.P.M.
RUN NUMBER
28'
24'
16'
8'
W.S.
SAMPLER
A
B
C
D
E
SET 1
STEP 3
SETS OF SAMPLES OBTAINED AT 5-MINUTE INTERVALS OPERATION REPEATED NINE TIMES (10 RUNS)
PROCEDURE
NOTES:
1 FIVE SAMPLES WERE OBTAINED SIMULTANEOUSLY IN EACH SET
2 BOTTOM SAMPLES ARE 2-FOOT FROM BOTTOM
CHARLESTON HARBOR, S. C.
SPECIAL RESEARCH OPERATION
SEDIMENT RESULTS - STEP 3

Figure 4

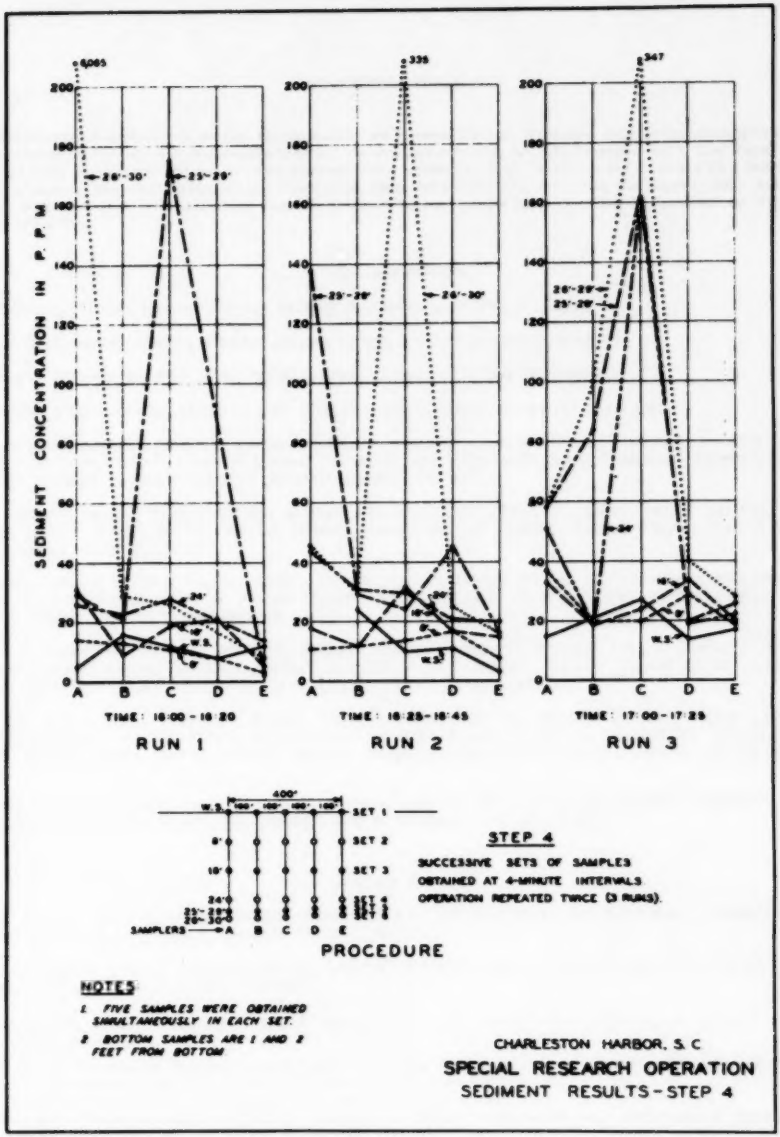
SEDIMENT CONCENTRATION IN P. P. M.
TIME: 16:00 - 16:20
RUN 1
TIME: 16:25 - 16:45
RUN 2
TIME: 17:00 - 17:25
RUN 3
STEP 4
SUCCESSIVE SETS OF SAMPLES OBTAINED AT 4-MINUTE INTERVALS OPERATION REPEATED TWICE (3 RUNS).
PROCEDURE
NOTES
1. FIVE SAMPLES WERE OBTAINED SIMULTANEOUSLY IN EACH SET.
2. BOTTOM SAMPLES ARE 1 AND 2 FEET FROM BOTTOM
CHARLESTON HARBOR, S. C
SPECIAL RESEARCH OPERATION
SEDIMENT RESULTS - STEP 4

Figure 5

PROCEEDINGS-SEPARATES

The technical papers published in the past twelve months are presented below. Technical-division sponsorship is indicated by an abbreviation at the end of each Separate Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways (WW) divisions. For titles and order coupons, refer to the appropriate issue of "Civil Engineering" or write for a cumulative price list.

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MARCH: 176(SA), 177(EM), 178(HY), 179(EM), 180(HY), D-123(HY), D-126(ST), D-128(ST).

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MAY: 189(HY), 190(HY), 191(CP) & (AT), 192(SM), 193(HY), D-129(PO), D-138(CP), D-145(ST).

JUNE: 194(CP) & (AT), 195(SM), 196(CP) & (AT), 197(HY), 198(ST), 199(EM), D-134(HY), D-141(HY).

JULY: [a] 200(SM)[b], 201(ST)[b], 202(EM)[b], 203(SM)[b], 204(AT)[b], 205(EM)[b], 206(ST)[b], 207(SA)[b], 208(SA)[b], 209(ST)[b], 210(SU)[b], 211(EM)[b], 212(SU)[b], 213(IR)[b], 214(HW)[b], 215(SM)[b], 216(ST)[b], 217(ST)[b], 218(ST)[b], 219(ST)[b], 220(SM)[b], 221(HW)[b], 222(SM)[b], 223(EM)[b], 224(EM)[b], 225(EM)[b], 226(CO)[b], 227(SM)[b], 228(SM)[b], 229(IR)[b].

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OCTOBER: [d] 290(all Divs), 291(ST)[c], 292(EM)[c], 293(ST)[c], 294(PO)[c], 295(HY)[c], 296(EM)[c], 297(HY)[c], 298(ST)[c], 299(EM)[c], 300(EM)[c], 301(SA)[c], 302(SA)[c], 303(SA)[c], 304(CO)[c], 305(SU)[c], 306(ST)[c], 307(SA)[c], 308(PO)[c], 309(SA)[c], 310(SA)[c], 311(SM)[c], 312(SA)[c], 313(ST)[c], 314(SA)[c], 315(SM)[c], 316(AT), 317(AT), 318(WW), 319(IR), 320(HW).

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DECEMBER: 359(AT), 360(SM), 361(HY), 362(HY), 363(SM), 364(HY), 365(HY), 366(HY), 367(SU)[e], 368(WW)[e], 369(IR), 370(AT)[e], 371(SM)[e], 372(CO)[e], 373(ST)[e], 374(EM)[e], 375(EM), 376(EM), 377(SA)[e], 378(PO)[e].

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JANUARY: 379(SM)[e], 380(HY), 381(HY), 382(HY), 383(HY), 384(HY)[e], 385(SM), 386(SM), 387(EM), 388(SA), 389(SU)[e], 390(HY), 391(IR)[e], 392(SA), 393(SU), 394(AT), 395(SA)[e], 396(EM)[e], 397(ST)[e].

FEBRUARY: 398(IR)[f], 399(SA)[f], 400(CO)[f], 401(SM)[f], 402(AT)[f], 403(AT)[f], 404(IR)[f], 405(PO)[f], 406(AT)[f], 407(SU)[f], 408(SU)[f], 409(WW)[f], 410(AT)[f], 411(SA)[f], 412(PO)[f], 413(HY)[f].

MARCH: 414(WW)[f], 415(SU)[f], 416(SM)[f], 417(SM)[f], 418(AT)[f], 419(SA)[f], 420(SA)[f], 421(AT)[f], 422(SA)[f], 423(CP)[f], 424(AT)[f], 425(SM)[f], 426(IR)[f], 427(WW)[f].

a. Beginning with "Proceedings-Separate No. 200," published in July, 1953, the papers were printed by the photo-offset method.
b. Presented at the Miami Beach (Fla.) Convention of the Society in June, 1953.
c. Presented at the New York (N.Y.) Convention of the Society in October, 1953.
d. Beginning with "Proceedings-Separate No. 290," published in October, 1953, an automatic distribution of papers was inaugurated, as outlined in "Civil Engineering," June, 1953, page 66.
e. Discussion of several papers, grouped by divisions.
f. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.

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